Measurement and Evolution Analysis of China's Agricultural New Quality Productivity Level Under the TOE Framework

Pan Liu, Weilin Nie, Dong Li

Abstract—**This paper constructs a comprehensive evaluation system of agricultural new quality productivity (ANQP) covering three levels: technology, organization, and environment, and is refined into five dimensions: new quality laborers, new quality means of production, new quality labor objects, new quality development methods, and new quality development environment, based on the TOE framework. Using panel data from 31 provinces in China from 2011 to 2021, the entropy method, Dagum Gini coefficient, kernel density estimation, and Markov chain are used to measure the development level of ANQP, and its regional distribution pattern and dynamic evolution characteristics are deeply analyzed. Founding that: (1) Although there are differences in the development level and growth rate of AANQP in various provinces in China, they are generally on a continuous upward trend. High-level regions play a leading role, while medium and low-level regions accelerate their catch-up, jointly promoting the evolution of the national development pattern towards a balanced direction. (2) The development level of ANQP in the nine major agricultural regions shows a significant gradient distribution, and regional differences are the main factor leading to overall unbalanced development. (3) There is a structural imbalance in dimensional development, with obvious differentiation of regional advantages. Different regions have their characteristics and shortcomings in specific dimensions. In terms of hierarchical development, the organizational level has the highest level of development, and there is still room for improvement in the levels of technology application and environmental optimization; (4) The spatial distribution of ANQP has converged from a multi-peak model to a single-peak model, and regional differences have narrowed, but the overall level is still low. There is a "club convergence" effect between regions. The development level of each province is highly sustainable, and it is difficult to upgrade across stages, but the upward transfer trend is significant.**

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Index Terms—**agricultural new quality productivity; TOE framework; regional difference.**

I. INTRODUCTION

IN September 2023, General Secretary Xi Jinping first proposed the concept of new quality productivity (NQP) during his inspection in Heilongjiang. In January 2024, during the collective study of the Political Bureau of the CPC Central Committee, he emphasized that it is innovation-led and has a substantial increase in total factor productivity. Its essence lies in advanced productivity, characterized by innovation with a core focus on quality. At the Third Plenary Session of the 20th CPC Central Committee in 2024, the General Secretary reiterated that NQP needs to be adapted to local conditions. As the core driving force for high-quality development, the development of NQP in the agricultural field to local conditions, is not only the key to promoting the comprehensive revitalization of rural areas, but also the core of the strategy of building agricultural power. Therefore, based on analyzing the connotation and characteristics of China's ANQP, it is of great theoretical and practical significance to study the multi-dimensional level measurement, regional differences, and dynamic evolution of China's ANQP.

The existing research on the measurement of ANQP is limited and mainly follows two research paths. First, based on the connotation of NQP and Marx's three-factor productivity theory, the research is carried out by constructing an NQP indicator system. For example, they constructed an indicator system of NQP covering the three dimensions (agricultural science and technology productivity, green productivity, and digital productivity) [1]-[3]. Focused on the three dimensions (laborers, labor objects, and labor materials), they built a corresponding indicator system [4]-[7]. Second, based on the connotation and economic model of NQP, some investigators discussed its influencing factors and enhancement pathways[8]. In addition, studies on the measurement of NQP in other fields pointed out that the development of NQP was influenced by multiple factors [10]-[12]. Therefore, scholars have innovatively constructed corresponding indicator systems from multiple dimensions such as technology, green, and digital [13]-[17], and assessed the impact on the company's growth or innovation [18]-[21]. From a systems theory perspective, NQP is a complex system composed of "elements-structure-functions" [22], and its development is greatly constrained by external environmental factors, such as social institutional changes [23]. This indicates that the formation of NQP is the result of the complex interplay of multiple factors, both inside and outside the system. The TOE theory has shown good effectiveness in exploring the influencing factors of complex systems [24], [25]. This theoretical framework integrates the three dimensions of technology, organization, and environment, and emphasizes the influence of their interactions on the construction of ANQP. The construction of an evaluation system for ANQP based on this framework can be comprehensively evaluated and avoid one-sidedness. At the same time, the system has high adaptability and can ensure the timeliness and accuracy of the results. In addition, it can effectively highlight the key role of technology in promoting the development of ANQP, and is closely related to external environmental factors such as national policies and industry development. However, the current research on the measurement of ANQP lacks analysis based on the comprehensive TOE theory and pays insufficient attention to the development environment factors (social development environment, policy environment, etc.) and development mode factors (green, sharing, open cooperation, etc.) of ANQP.

The existing research has the following deficiencies: (1) The construction of the evaluation index system for the development level of ANQP in China is still insufficient. (2) Few studies conduct in-depth research based on the TOE framework. (3) There is insufficient attention paid to the development environment of ANQP (including the social and policy environment).

Therefore, it is urgent to construct an indicator system of ANQP based on the TOE theoretical framework to more systematically explore its development level, regional differences, and evolutionary characteristics. This paper integrates Marx’s three-factor theory of productivity with the TOE framework, deeply analyzes the theoretical connotation and characteristics of ANQP, and constructs a comprehensive evaluation system of ANQP covering three aspects of technology, organization, and environment, which is specifically refined into five key dimensions: new quality laborers, new quality means of production, new quality labor objects, new quality development concept, and new quality development environment. Then, by employing multiple methods to conduct in-depth analysis of regional disparities and their dynamic evolution, thereby providing effective recommendations and countermeasures for the development of ANQP.

II. Research Design

A. Connotation and Characterization Of ANQP

As the leader of advanced productivity evolution, the essence of NQP stems from the revolutionary breakthrough of technology, innovative integration of production factors, and profound transformation of industrial structure. Based on Marx’s theory of the three elements of productivity and the TOE framework, this paper deeply analyzes the connotation of the ANQP and advocates the analysis from three levels: technology, organization, and environment, and specifically subdivided into five key dimensions: new quality laborers, new quality means of production, new quality labor objects, new quality development concept, and new quality development environment.

(1) Technological level. New quality means of production is the core driving force for the leap of ANQP. It covers a wide range from physical production materials, such as agricultural meteorological stations and cables, to intangible knowledge capital, such as R&D investment. Among them, scientific and technological innovation is the lifeline for the development of ew quality means of production. The level of agricultural mechanization, the improvement of information infrastructure, and the enhancement of grain production capacity serve as its solid support.

(2) Organizational level. The deep integration of new quality labor objects and new quality laborers constitutes the cornerstone of the development of ANQP. Scientific and technological innovation and progress are placed at the core of leading the sustainable development of agriculture, emphasizing that agricultural enterprises, as the main body of innovation, should actively lead the research and development and application of key areas such as advanced breeding technology and agricultural informatization. At the same time, high-quality agricultural labor, with its ability to quickly master new technologies and efficiently apply them, has become the key to meeting the needs of ANQP. In addition, agricultural organizations need to actively cultivate a sense of sustainable development, prioritize resource consumption, environmental pollution, and environmental protection, and ensure the long-term sustainability of agricultural production.

(3) Environmental level. The cultivation of ANQP cannot be separated from a good development environment as a foundation. This includes both the fair and transparent market transactions of agricultural products, the healthy and orderly development of the industry, and other social and economic environments, and the natural environmental factors that affect agricultural production efficiency and output. Building a comprehensive environment conducive to the development of ANQP is the key to ensuring its continued growth and effectiveness.

B. Indicator Construction and Data Sources

Based on a deep understanding of the connotation and characterization of ANQP and integrating existing literature, this paper constructs a comprehensive evaluation index system of ANQP covering technology, organization, and environment. (see Table I). Considering the regional differences, the indicators need to be flexibly adjusted in practical application to ensure the effectiveness of the study and the operability of the results.

Meanwhile, according to the “Comprehensive Agricultural Zoning of China”, 31 provinces are divided into nine agricultural zones, which are as follows: Northeast Region (Region A): Heilongjiang, Jilin, and Liaoning provinces; Inner Mongolia Great Wall Region (Region B); Huang-Huai-Hai Region (Region C): Beijing, Tianjin, Hebei, Shandong, Henan provinces and one municipality; Loess Plateau Region (Region D): Shaanxi, Shanxi, and Ningxia provinces; Yangtze River Mid-Lower Reaches Region (Region E): Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Zhejiang, Shanghai, and Fujian provinces and municipalities;

Southwest Region (Region F): Sichuan, Chongqing, Yunnan, and Guizhou provinces and municipalities; Gansu New Region (Region G): Gansu and Xinjiang provinces; Qinghai-Tibet Region (Region H): Tibet and Qinghai provinces; South China Region (Region I): Guangdong, Hainan, and Guangxi provinces. This partition further refines the analysis of inter-regional differences.

The sample data cover the panel data of 31 provinces in China from 2011 to 2021 and are derived from the official website of the National Bureau of Statistics, China Statistical Yearbook, China Rural Statistical Yearbook, China Environmental Statistical Yearbook, China Energy Statistical Yearbook, and other official and authoritative publications. For a small number of missing values, this paper adopts the interpolation method for reasonable estimation and processing to ensure data completeness and reduce sample loss.

III. Level Measures and Regional Analysis

This paper utilizes the entropy value method to accurately quantify the development level of ANQP in 31 provinces of China. Fig. 1 shows the research method diagram.

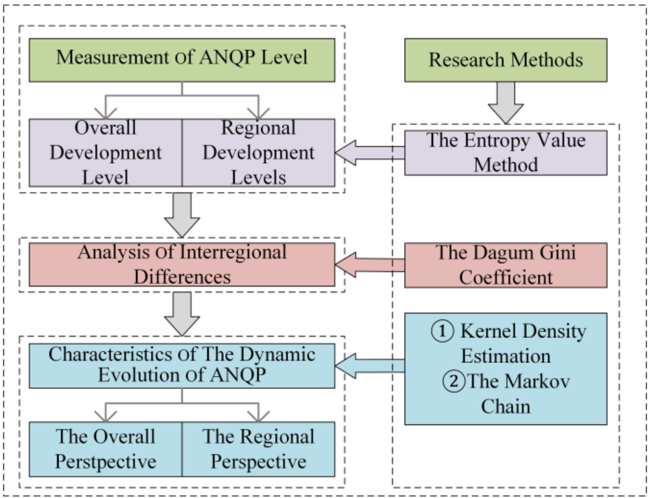

Fig. 1. Research method diagram

A. Overall Development Level

Fig. 2 shows the evolution of the distribution of China's ANQP from 2011 to 2021. Specifically, the growth rate has experienced a slow decline, then a sharp rise, and then a slowdown. 2011 to 2015 saw steady growth, and the growth rate further stabilized and accelerated in 2021, a trend that closely matches the National Plan for Sustainable Agricultural Development (2015-2030), which promotes the development of ANQP in China. Since 2019, benefiting from the 37 policies jointly launched by the Ministry of Agriculture and Rural Affairs and the Ministry of Finance to strengthen agriculture and benefit agriculture, covering multiple key areas, the development of ANQP has accelerated significantly.

B. Regional Development Level

The results of measuring the development level of ANQP in China's provinces and nine agricultural regions from 2011-2021 are shown in Table II.

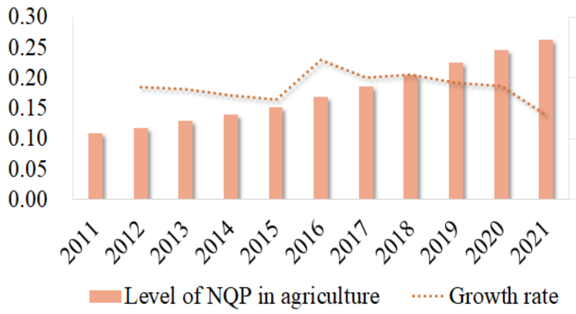

Fig. 2. Level and rate of growth of NQP in agriculture, 2011-2021

At the provincial level, the trends in each province are consistent with the national trend, but there are significant differences. In some cases, such as Tianjin, its ANQP in 2021 is far lower than the national average and the 2011 level of most provinces. Qinghai and Ningxia also face similar challenges, and the low level exacerbates regional imbalances. On the contrary, Guangdong and Jiangsu exceeded 0.5, followed closely by Sichuan and Shandong, reflecting high-level development. For low-level provinces, Tianjin is mainly affected by industrial positioning, while Qinghai and Ningxia are restricted by geographical conditions.

Among the nine major agricultural regions, in 2021, the development level of ANQP in South China is 0.3581, followed by the Southwest Region and the middle and lower reaches of the Yangtze River, both showing high levels with values above 0.3. In contrast, Qinghai-Tibet Region the development level in 2021 is only close to Gan-Xin District in 2011 and far less than other regions. On the whole, the development of ANQP in China presents a diversified pattern. In the future, continued efforts are needed to promote balanced progress.

Table III reveals the regional differences in development rates among provinces and nine major agricultural regions. Guizhou leads the country with a growth rate of 42.16%, and Yunnan, Hainan, Hunan, Sichuan, and other places have achieved remarkable results with growth rates exceeding 20%. However, the growth rate in Tibet and Jilin is relatively low, and the growth rate in many other provinces is between 5% and 10%. Affected by factors such as geographical location and strategic positioning, they show different development potential. These differences highlight the need for differentiated policy implementation. The order of regional development levels from high to low is South China, the middle and lower reaches of the Yangtze River, the Huang-Huai-Hai District, Southwest District, Inner Mongolia Great Wall Area, Northeast District, Loess Plateau District, Gansu-Xinjiang District, and the Qinghai-Tibet District. In terms of growth rate, the Southwest Region ranked first with 28.08%, followed by the Gansu-Xinjiang Region, and Qinghai-Tibet Region at the bottom with 6.50%. The growth rate ranking does not exactly correspond to the mean ranking, highlighting the diversity and differences in development between regions. It is worth noting that high-level areas may not necessarily grow the fastest, while low-level areas may show significant progress, which is deeply affected by geographical location and industrial positioning.

TABLE III
DEVELOPMENT LEVEL AND GROWTH RATE OF ANQP

Region	Average	Ranking	Growth Rate	Ranking
Beijing	0.1052	24	9.87%	22
Tianjin	0.0528	30	8.41%	24
Hebei	0.2244	8	11.32%	19
Shanxi	0.0948	27	8.08%	26
Inner Mongolia	0.1449	18	7.76%	28
Liaoning	0.1297	19	7.77%	27
Jilin	0.1114	23	5.15%	31
Heilongjiang	0.1701	15	7.13%	29
Shanghai	0.1257	21	13.95%	15
Jiangsu	0.4031	1	11.00%	20
Zhejiang	0.2045	12	12.56%	17
Anhui	0.2072	11	19.35%	7
Fujian	0.1792	14	18.84%	8
Jiangxi	0.1482	16	14.42%	14
Shandong	0.3339	3	12.62%	16
Henan	0.3152	4	12.24%	18
Hubei	0.1955	13	16.14%	11
Hunan	0.2340	6	23.87%	4
Guangdong	0.3827	2	14.58%	13
Guangxi	0.2253	7	9.56%	23
Hainan	0.1029	25	29.77%	3
Chongqing	0.0993	26	17.32%	10
Sichuan	0.2953	5	23.58%	5
Guizhou	0.1474	17	42.16%	1
Yunnan	0.2082	10	34.46%	2
Tibet	0.0651	28	5.53%	30
Shannxi	0.2204	9	10.78%	21
Gansu	0.1149	22	18.32%	9
Qinghai	0.0391	31	8.25%	25
Ningxia	0.0611	29	16.13%	12
Xinjiang	0.1294	20	19.67%	6
Zone A mean	0.1371	6	2.99%	8
Zone B mean	0.1449	5	2.67%	7
Zone C mean	0.2063	3	5.10%	5
Zone D mean	0.1254	7	4.17%	6
Zone E mean	0.2122	2	7.29%	3
Zone F mean	0.1875	4	12.16%	1
Zone G mean	0.1222	8	8.21%	2
Zone H mean	0.0521	9	2.92%	9
Zone I mean	0.2369	1	6.07%	4

The Qinghai-Tibet region has a high altitude, low temperature, limited enzyme activity, low metabolic efficiency, and anoxic environment, which hinders the growth of crops. In addition, the complex geographical environment brings difficulties in the implementation of agricultural facilities and technologies, which have jointly restricted its rapid development. On the contrary, the Southwest region has shown excellent development potential and advantages despite its complex climate, relying on its solid agricultural foundation, rich resources, suitable natural environment, and leading water resources in the country.

C. Level of Development by Dimension

Table IV shows in detail the development status of the nine agricultural regions at each level and dimension. The development level of ANQP in the nine major agricultural regions shows a similar state at all levels, with the organizational level leading by far, followed by the environmental level and the technical level. However, the growth rates are different.

The Northeast region has increased at the organizational level (20.08%), and the environmental level has declined the fastest (-10.55%). The Inner Mongolia Great Wall region has declined at the organizational level (-20.14%), and the environmental level has grown the fastest (11.36%). The Huang-Huai-Hai region has led the growth rate at the organizational level (22.11%), and the decline rate at the technical and environmental levels has remained above 10%. The three dimensions of the organizational level in the Loess Plateau region improved, and the technical and environmental levels decreased and increased at a rate of about 8%. The three dimensions in the middle and lower reaches of the Yangtze River and the southwest region increased, and the organizational level grew the fastest (31.41% and 39.4%). Tthe three dimensions in the Gansu-Xinjiang region grew, and the technical and organizational levels grew at a similar rate (24.42% and 24.09%). Tthe organizational level in the Qinghai-Tibet region grew the fastest (37.96%), and the environmental level declined unilaterally (-13.81%). The organizational level in South China had the fastest growth rate (27.54%), and the technical level grew less than 1%.

The nine major agricultural regions perform differently in various dimensions of ANQP. Although new quality development concept is at the forefront (following new quality laborers, labor objects, and the environment), the development of new quality means of production is relatively lagging, showing that there is still room for improvement. In terms of growth rate, the performance of each region is different. Northeast China leads the new quality development concept with a growth rate of 35.36%, while the level of new quality laborers has dropped significantly (-36.17%). The new quality development environment in the area along the Great Wall in Inner Mongolia has the fastest growth rate (11.36%), but the new quality development concept has experienced a -22.8% decline. The growth rate of new quality labor objects in Huanghua Hai District was as high as 69.52%, while the environment dropped slightly (-7.19%). In the Loess Plateau and the middle and lower reaches of the Yangtze River, the new quality development concept grew at a rate of 20.67% and 57.71%, respectively. In the former, only new quality means of production declined (-8.19%), while in the latter, new quality laborers declined slightly (-3.07 %). Southwest and South China are all improving, with positive growth in all five dimensions, especially the new quality development concept, which has a significant growth rate, reaching 60.05% and 70.23% respectively. The growth rate of new quality labor objects in the Gan-Xin District is also impressive, at 66.92%.

Further analysis of the sub-dimensions shows that South China ranks first in new quality means of production, labor objects, and development concepts, and the growth rate of development concepts is also the fastest (70.23%). In terms of new quality laborers, the Northeast region has the highest development level, and the Qinghai-Tibet region has the fastest growth rate. The middle and lower reaches of the Yangtze River lead in the new quality development environment, while the Southwest region has the fastest growth rate in this dimension. Overall, the new quality development concept continues to grow rapidly, highlighting the core position of green development.

D. Analysis of Interregional Differences

The Dagum Gini coefficient [26] was used to analyze the differences in the development of ANQP levels in nine agricultural regions. The results are shown in Figs 3 and 4.

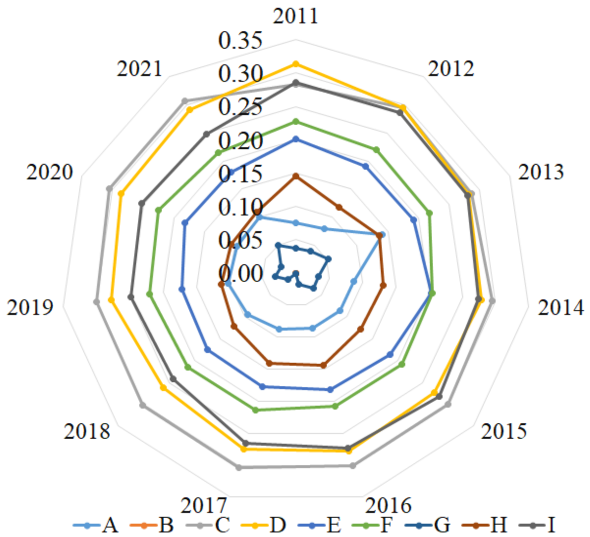

Fig. 3. Gini coefficients within groups, 2011-2021

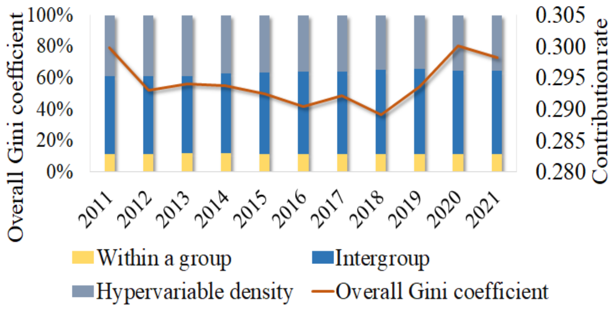

Fig. 4. Analysis of differences in the level of ANQP, 2011-2021

Fig. 3 shows the changes in the Gini coefficient of the nine major agricultural regions from 2011 to 2021. Overall stable, with significant fluctuations in individual years and regions. The Gini coefficient of the Huang-Huai-Hai District is high and stable, reflecting large and sustained development differences. The South China region and the Loess Plateau region were similar at the beginning but differentiated after 2018, with the difference between the former narrowing and the latter expanding. The trend in the middle and lower reaches of the Yangtze River is opposite to that in the southwestern region, and the changes in the Gini coefficient are mirror-symmetrical. The area along the Yangtze River in Inner Mongolia has a Gini coefficient of 0 due to a single city. The Northeast Region experienced large fluctuations in 2013, showing internal unevenness. The Gini coefficient of the Gansu-Xinjiang District was nearly 0 from 2011 to 2017, indicating balanced development, but it increased after 2017. The Gini coefficient of the rest of the regions fluctuates around 0.15, indicating unstable development and differences in rates of ANQP.

Fig. 4 shows the dynamic changes of the Gini coefficient and contribution rate. The Gini coefficient generally showed a trend of first falling and then rising. Although there were slight fluctuations in 2017, it was stable at around 0.29. The trends of hypervariable density and contribution rate between groups are similar. The former decreases first, then increases, and then stabilizes, while the latter first increases, then decreases, and then stabilizes; the contribution rate within groups fluctuates slightly. During the study period, differences between groups had the most significant impact on overall differences, followed by differences within groups. This is mainly attributed to differences in natural resources, technological levels, and basic conditions among various regions, resulting in uneven development levels and speeds.

IV. Characteristics Of The Dynamic Evolution Of ANQP

A. Spatial Evolution of the Level of ANQP in the Overall Perspective

This paper uses a high-density Gaussian function model to estimate the time evolution characteristics of China's ANQP development level from 2011 to 2021. The results are shown in Fig. 5.

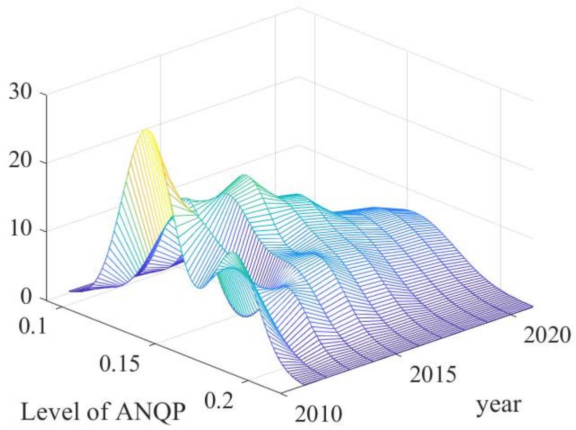

Fig. 5. National level of development of NQP in agriculture

The main findings include: (1) The spatial distribution changes from multimodal to unimodal, indicating that regional differences have significantly narrowed and become stable, but the overall level is low, with an average value of about 0.2. (2) From 2011 to 2016, high-level regions dominated development. As time went by, medium- and low-level regions gradually emerged, forming a balanced development trend. (3) The center of the curve shifts to the right, reflecting the continued improvement in the level of ANQP, which is affected by multiple factors such as industrial positioning, geographical location, development foundation, and policy support. (4) The height of the wave crest decreases and the width increases, reflecting the gradual narrowing of differences between regions. Although the improvement speed is different, the overall development difference is decreasing. (5) The right tail phenomenon has weakened, indicating that the imbalance of development across the country is gradually improving, and all regions are committed to improving ANQP.

In summary, China's ANQP is increasing and tending to be stable, and regional differences are narrowing, but the overall level is still low. In the future, we need to adapt to local conditions, optimize strategies, and promote balanced and efficient development among regions.

B. Spatial Evolution of ANQP Levels from Regional Perspective

As shown in Fig. 6, the Inner Mongolia Great Wall area, Huanghua Hai area, Qinghai-Tibet area, and South China area show a single peak shape, reflecting that the development of ANQP among provinces is relatively balanced. The peaks in the Qinghai-Tibet area fluctuate, indicating that the internal development differences are caused by uneven growth rates; the peaks in the South China area decrease, indicating that the internal differences are gradually narrowing. The peaks in the Huanghua Hai area move steadily to the right, and the regional differences have improved. The Northeast and Southwest areas have changed from multi-peaks to single peaks, the regional differences have decreased, and the productivity levels have increased. The Loess Plateau area has changed from a single peak to a double peak, reflecting the intensification of internal multi-level differentiation, but the height of the peaks has decreased, indicating that the differences have eased. The Gansu-Xinjiang area has a complex shape. Except for 2016-2018, the peaks are flat, indicating regional balance; the peaks increased sharply during this period, indicating that individual provinces have developed rapidly, widening the gap, and then the gap gradually narrowed. The Inner Mongolia Great Wall area has no intra-group differences due to a single province, and the image is symmetrical. Although the Qinghai-Tibet region is similar to Inner Mongolia, the fluctuation of peaks shows that regional differences increase and decrease from time to time, which is affected by the internal development rate.

Based on kernel density estimation, the Markov chain is introduced to further analyze the development level of ANQP in Chin. About existing research on this methodology [27], using the traditional Markov chain to construct a 31×31 transition probability matrix, the probability that the ANQP of the sample province transfers from the level E_i in the year t to the level E_j in the year t+1 is:

$$P_{ij}\left(E_{\mathrm{i}} \longrightarrow E_{j}\right)=\frac{n_{ij}}{n_{i}} \quad (1)$$

Among them, n_{ij} represents the total number of provinces at the levels i to j and n_i represents the number of provinces with level E_i at level i.

Based on the sample data, the development level of ANQP in various provinces in China is divided into four categories: low (0.0286-0.0954), relatively low (0.0954-0.1506), relatively high (0.1506-0.2337), and high (0.2337-0.5769), with 1 to 4 representing them respectively. The analysis shows that: (1) The probability of each category on the diagonal remaining the same is much higher than that on the off-diagonal, with the lowest value reaching 0.7738, indicating that the development level of each province will be stable in the future. (2) There is a "club convergence" phenomenon, and productivity tends to gather within a high (low) level. (3) The maximum probability of the off-diagonal line of 0.2262 is much lower than the minimum value of the diagonal line, indicating that it is difficult to transfer across stages. (4) The probability of productivity shifting downward is extremely low, such as the probability of falling from a lower level to a lower level is 0, while the upward shift trend is obvious, such as the probability of shifting from a higher level to a higher level (0.1733) is higher than the probability of falling to a lower level (0.0267).

This paper adopts the spatial Markov chain model to deeply analyze the spatial evolution characteristics of ANQP in China. Analyze spatial dynamics by drawing on commonly used research methods [28], [29], the specific results are shown in Table V. Compared with the traditional Markov chain, this study found that the probability of the province moving from level 3 to level 4 is significantly affected by the level of surrounding provinces. Specifically, if the neighboring province is at level 2, the transition probability is 0.0526, which is significantly lower than the traditional model (0.1733). On the contrary, if the neighboring province is at level 3, the transition probability increases to 0.2424, which is higher than the traditional value.

Further analysis shows that the dynamic transfer process of ANQP is significantly affected by the spatial distribution pattern. When adjacent to a high-level province, the probability of the province developing to a higher level increases; while adjacent to a low-level province, the opposite trend is shown. Finally, the study revealed the synergy between the development level of ANQP in each province and adjacent regions: when the province is adjacent to a province with level 1, the probability of its ANQP remaining at level 1 in the initial year is relatively high, reflecting the regional mutual influence and dependence between regions.

Through dynamic evolution analysis, the development of ANQP in China is affected by geographical location, showing a spatial spillover effect. Specifically, high-level regions have a positive impact on low-level regions, increasing the probability of the latter's transfer to high levels. Conversely, low-level regions may have a certain degree of inhibition on the development of surrounding high-level regions, reducing the probability of their further development, forming a negative effect. From a spatial perspective, this phenomenon is manifested as the accelerated development of high-level regions, while the relatively lagging development of low-level regions shows a dynamic relationship between the two, tending to polarization.

To empirically examine whether geographical location has a statistically significant effect on the development of ANQP in China, it will be verified by commonly used testing methods[30]. The null hypothesis is that the transfer of ANQP levels is spatially independent, and the transfer probability of development levels has nothing to do with the type of spatial lag, so traditional Markov chain calculations can be directly used. The results show that at the significant level of 36 degrees of freedom and α=0.005, Q=59.893, P=0, rejecting the null hypothesis, thus statistically verifying that the development of ANQP levels is related to geographical location(see Table VI).

TABLE V
TRADITIONAL MARKOV TRANSFER PROBABILITY MATRIX FOR ANQP

n	t	t+1			
		1	2	3	4
81	1	0.8519	0.1481	0	0
84	2	0	0.7738	0.2262	0
75	3	0	0.0267	0.8	0.1733
70	4	0	0	0	1

TABLE VI
SPATIAL MARKOV TRANSFER PROBABILITY MATRIX FOR ANQP

Proximity type	n	t+1				
		t	1	2	3	4
1	10	1	0.9	0.1	0	0
	5	2	0	0.6	0.4	0
	6	3	0	0	1	0
	0	4	0	0	0	0
2	38	1	0.8421	0.1579	0	0
	38	2	0	0.7895	0.2105	0
	19	3	0	0.1053	0.8421	0.0526
	9	4	0	0	0	1
3	25	1	0.84	0.16	0	0
	27	2	0	0.7778	0.2222	0
	33	3	0	0	0.7576	0.2424
	25	4	0	0	0	1
4	8	1	0.875	0.125	0	0
	14	2	0	0.7857	0.2143	0
	17	3	0	0	0.7647	0.2353
	36	4	0	0	0	1

V. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

This study innovatively integrates the TOE framework with Marx's three-factor productivity theory, constructs a three-level, five-dimensional evaluation system, uses entropy method and other methods, and conducts multidimensional empirical analysis based on provincial panel data from 2011 to 2021, breaking through the limitations of existing research and providing a new perspective for revealing the evolution law of ANQP. The core conclusions are as follows.

(1) Overall trend. The growth rate of ANQP in China has experienced a phased change of "slow decline - rapid rise - slowdown in growth", but it has maintained an upward development trend overall. High-level regions have played a leading role, and medium and low-level regions have accelerated their catch-up, jointly promoting the evolution of the national development pattern towards a balanced direction.

(2) Regional development. The development levels of ANQP in the nine major agricultural regions are distributed in a gradient: the levels in South China and the middle and lower reaches of the Yangtze River are relatively high, while those in the Qinghai-Tibet region are relatively low. In terms of growth rate, Southwest China ranks first, Gansu-Xinjiang region ranks second, and Qinghai-Tibet region ranks last. Different agricultural regions have different resource endowments, policy support, industrial foundations, etc., and their growth momentum varies significantly. There are differences in differences in the development levels of ANQP within the nine major agricultural regions. For example, the differences in the development of ANQP in the Huanghuaihai region are significant and have not improved for a long time. Some regions have narrowed their differences, such as South China, while others still have differentiation, such as the Loess Plateau. The differences between groups have a significant impact on the overall differences in the level of ANQP across the country, and the coordination and complementarity between regions still need to be strengthened.

(3) Dimensional and hierarchical development. Dimensional development: New quality development concept is leading, but new quality means of production is relatively lagging, and there is a structural imbalance. Regional advantages are differentiated. The level of new quality laborers in the Northeast is the highest, and the Qinghai-Tibet region has the fastest growth in this dimension; the new quality development environment in the middle and lower reaches of the Yangtze River is leading, and the southwest region has the fastest growth in this dimension, reflecting the characteristics and shortcomings of different regions in the development of each dimension. Hierarchical development: The organizational level has the highest level of development, and the environmental and technical levels are similar and second, indicating that agricultural development has a certain foundation in organizational coordination and other aspects, but there is still room for improvement in technology application, environmental optimization, and other levels.

(4) Spatial evolution. The spatial distribution of ANQP converges from a multi-peak model to a unimodal model, and regional differences are narrowed, but the overall level is still low (average is about 0.2). High-level regions have positive spillovers to the surrounding areas, and low-level regions have inhibitory effects ("club convergence"). Markov chain analysis shows that the development level of each province is highly sustainable, and it is difficult to upgrade across stages, but the upward transfer trend is significant.

B. Recommendations

(1) Optimize regional layout and promote coordinated development. Given significant regional differences, implement differentiated support policies: strengthen innovation leadership and technology spillover in high-level regions to drive surrounding areas; strengthen infrastructure and technology investment in medium and low-level regions to narrow the gap. At the same time, establish a cross-regional factor flow mechanism to promote efficient resource allocation and accelerate the overall balancing process.

(2) Strengthen technological innovation and promote structural upgrading. Focus on solving the structural imbalance of technology, organization and environment: in terms of technology, focus on breakthroughs in key areas such as intelligent agricultural machinery and biological breeding to accelerate the transformation of results. In terms of organization, enhance the collaborative capabilities of new business entities and use digitalization to optimize factor allocation; in terms of environment, improve green and low-carbon policies and build a smart agricultural platform. Through multi-dimensional collaboration, a development pattern of technology-led, organizational optimization and environmental support will be formed.

(3) Improve the monitoring mechanism and implement precise regulation. Consider its path-dependent characteristics, establish a dynamic monitoring and

evaluation system, regularly and scientifically analyze regional levels, and identify lagging regions. Implement step-by-step policy intervention: strengthen the basic capacity building of low-level regions, and focus on innovation incentives in medium- and high-level regions. And through financial support and regional cooperation, break the "club convergence" effect and promote the balanced improvement of ANQP across the country.

C. Significance

This study provides a key basis for the government to optimize policies and for agricultural operators to improve the development level, and has certain practical significance.

(1) Government level. The study of clear regional differences and evolutionary laws of ANQP has laid a scientific foundation for the formulation of precise coordination policies. The government needs to strengthen overall coordination, clarify the priority paths of technology spillovers, build a cross-regional cooperation mechanism, and establish a gap risk warning and precise assistance system to effectively prevent the polarization effect of "the strong get stronger and the weak get weaker" and promote regional coordination and progress.

(2) At the level of agricultural business entities. Based on the revealed spatial spillover and "club convergence" characteristics, business entities should implement differentiated layout strategies: entities in high-level regions should rely on their advantages in technology and talent aggregation to actively expand cross-regional cooperation; entities in low-level regions need to take the initiative to leverage policy dividends, focus on making up for the shortcomings in environmental optimization and technological innovation, break through development bottlenecks and achieve a leap in capabilities.

D. Future Research

Although this study uses a variety of methods to deal with dynamic changes and complex interactive effects, it still has certain limitations: First, at the method level, the accurate capture of spatial spillover effects and nonlinear evolution characteristics is still insufficient. Second, the data period is limited, and it may be difficult to fully reflect the latest developments in the agricultural field in recent years. In addition, the analysis perspective mainly focuses on the macro level of the whole country and the nine major agricultural regions, and does not pay enough attention to the subdivided regional differences within each province. Given these identified limitations, subsequent research will focus on improvement and deepening.

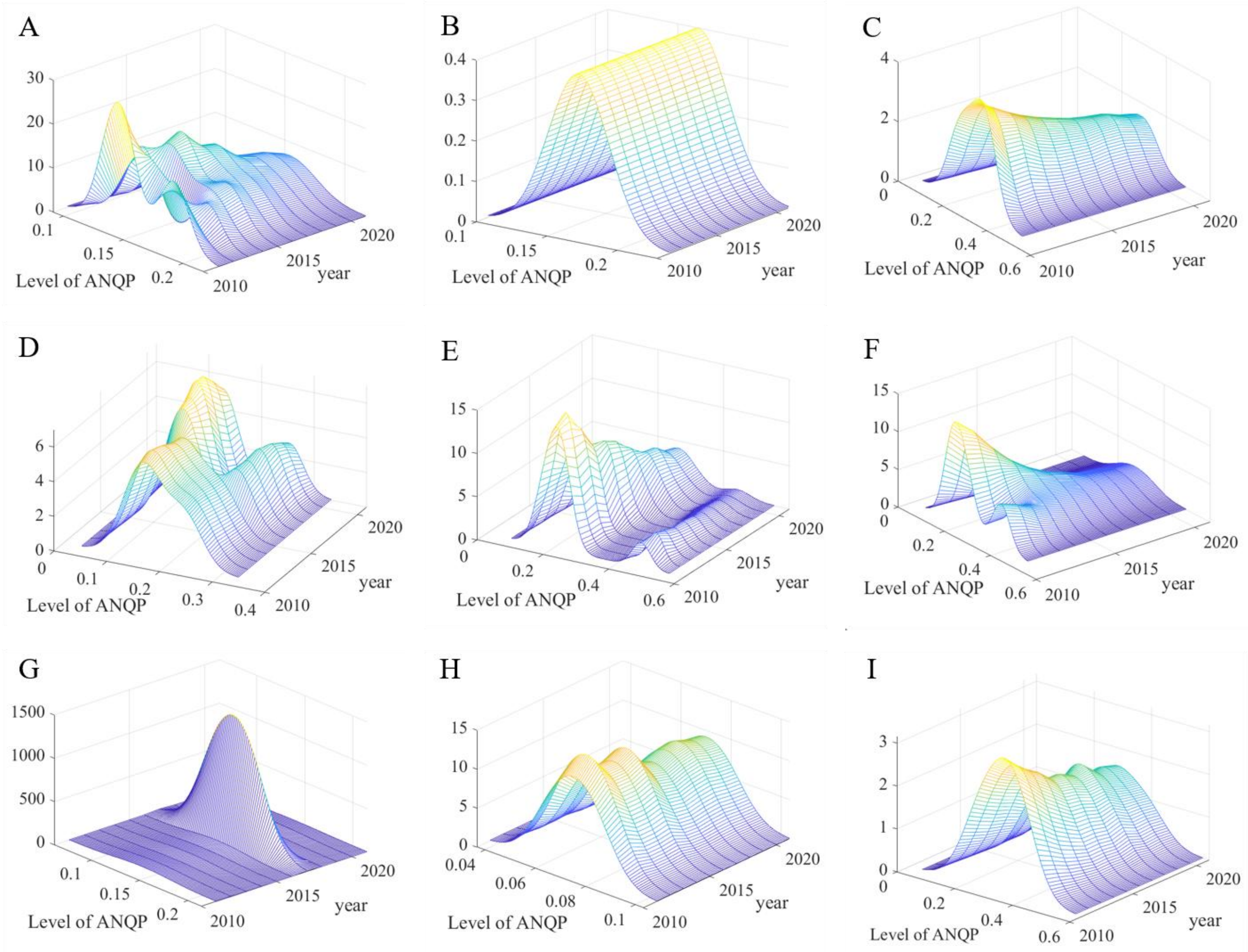

Fig. 6. Levels of ANQP in the nine agricultural regions

TABLE I
COMPREHENSIVE EVALUATION INDEX SYSTEM OF ANQP

Aspect	Dimension	Primary indicator	Secondary Indicators	Metrics	Attributes
T	new quality means of production	level of agricultural science and technology	science and technology innovation	agricultural science and technology employees (x1)	Positive
				agricultural S&T input (x2)	Positive
				R&D expenditure (x3)	Positive
				R&D personnel (x4)	Positive
			level of agricultural mechanization	total power of agricultural machinery and machinery (x5)	Positive
			grain production capacity	total grain production (x6)	Positive
		agricultural information development	information infrastructure development	number of agrometeorological station observations (x7)	Positive
				number of rural broadband access users (x8)	Positive
				length of fiber optic cable lines per square meter (x9)	Positive
O	new quality labor objects	the scale of a technological organization (organizational perceived capacity)	above-scale agriculture-related enterprises	number of agricultural production enterprises (x10)	Positive
				number of agricultural enterprises (x11)	Positive
				agricultural breeding enterprises (x12)	Positive
				number of pesticide and fertilizer enterprises (x13)	Positive
				number of agricultural logistics enterprises (x14)	Positive
	new quality development concept	organizational development concept (organizational sustainability)	resource consumption	water consumption in agriculture (x15)	Negative
				agricultural electricity consumption (x16)	Negative
			environmental pollution	fertilizer application (x17)	Negative
				pesticide application (x18)	Negative
			environmental protection	soil erosion control area (x19)	Positive
				forest cover (x20)	Positive
	new quality laborers	labor force development level	educational attainment	years of education per rural laborer (x21)	Positive
			per capita output value of primary industry	output value of primary industry/number of employees in primary industry (x22)	Positive
			per capita income of rural residents	per capita disposable income of rural residents (x23)	Positive
E	new quality development environment	market transaction environment	transaction scale	gross agricultural output (x24)	Positive
		natural environment	water resources	total water resources (x25)	Positive
			land resources	total land resources (x26)	Positive
		industry development environment	value added to the industry	GDP output value-added of primary industry (x27)	Positive
				value added of tertiary industry (x28)	Positive
			external environment	water resources irrigation level (x29)	Positive
				total retail sales of consumer goods (x30)	Positive

TABLE II
RESULTS OF MEASURING THE LEVEL OF NQP DEVELOPMENT IN CHINESE AGRICULTURE, 2011-2021

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
National Average	0.1083	0.1183	0.1290	0.1401	0.1516	0.1690	0.1860	0.2052	0.2249	0.2459	0.2630
Medium	0.0948	0.1076	0.1107	0.1228	0.1307	0.1450	0.1578	0.1805	0.1973	0.2065	0.2179
Beijing	0.0718	0.0764	0.0838	0.0930	0.0981	0.1028	0.1097	0.1169	0.1287	0.1337	0.1426
Tianjin	0.0381	0.0425	0.0465	0.0497	0.0517	0.0538	0.0538	0.0562	0.0575	0.0613	0.0701
Hebei	0.1591	0.1498	0.1801	0.1755	0.1858	0.2040	0.2284	0.2563	0.2786	0.3113	0.3391
Shanxi	0.0709	0.0748	0.0793	0.0840	0.0892	0.0894	0.0955	0.1033	0.1094	0.1190	0.1282
Inner Mongolia	0.1144	0.1052	0.1169	0.1228	0.1298	0.1403	0.1480	0.1608	0.1695	0.1832	0.2032
Liaoning	0.0981	0.1094	0.1102	0.1124	0.1145	0.1236	0.1296	0.1415	0.1506	0.1622	0.1744
Jilin	0.0912	0.0970	0.0977	0.1001	0.1033	0.1085	0.1137	0.1178	0.1247	0.1335	0.1382
Heilongjiang	0.1272	0.1379	0.1794	0.1472	0.1506	0.1590	0.1679	0.1805	0.1973	0.2065	0.2179
Shanghai	0.0736	0.0829	0.0914	0.1057	0.1169	0.1277	0.1375	0.1461	0.1576	0.1670	0.1762
Jiangsu	0.2635	0.2888	0.3091	0.3679	0.3721	0.4081	0.4229	0.4426	0.4816	0.5238	0.5533
Zhejiang	0.1285	0.1489	0.1569	0.1676	0.1849	0.1963	0.2094	0.2361	0.2589	0.2724	0.2899
Anhui	0.1099	0.1233	0.1375	0.1766	0.1762	0.1975	0.2187	0.2489	0.2671	0.3006	0.3226

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Fujian	0.0948	0.1100	0.1220	0.1343	0.1493	0.1757	0.1953	0.2159	0.2483	0.2524	0.2734
Jiangxi	0.0886	0.1076	0.1045	0.1134	0.1307	0.1450	0.1564	0.1694	0.1927	0.2055	0.2164
Shandong	0.2165	0.2389	0.2599	0.2819	0.3022	0.3207	0.3488	0.3734	0.3977	0.4434	0.4898
Henan	0.1976	0.2114	0.2422	0.2686	0.2905	0.3170	0.3444	0.3660	0.3765	0.4131	0.4394
Hubei	0.1110	0.1233	0.1364	0.1547	0.1730	0.1915	0.2116	0.2334	0.2521	0.2730	0.2901
Hunan	0.1118	0.1295	0.1397	0.1654	0.1938	0.2251	0.2556	0.2864	0.3251	0.3631	0.3788
Guangdong	0.2347	0.2550	0.2706	0.2862	0.3184	0.3636	0.4074	0.4511	0.4999	0.5458	0.5769
Guangxi	0.1624	0.1733	0.1762	0.1797	0.1934	0.2092	0.2347	0.2530	0.2841	0.2943	0.3176
Hainan	0.0452	0.0501	0.0577	0.0668	0.0715	0.0917	0.1090	0.1434	0.1512	0.1656	0.1797
Chongqing	0.0563	0.0612	0.0671	0.0777	0.0851	0.0972	0.1100	0.1174	0.1271	0.1394	0.1537
Sichuan	0.1472	0.1669	0.1819	0.1992	0.2298	0.2666	0.3186	0.3576	0.4107	0.4750	0.4944
Guizhou	0.0530	0.0680	0.0753	0.0886	0.1085	0.1312	0.1578	0.1899	0.2184	0.2545	0.2765
Yunnan	0.0820	0.0951	0.1107	0.1354	0.1607	0.1942	0.2272	0.2717	0.3043	0.3442	0.3646
Tibet	0.0521	0.0512	0.0548	0.0565	0.0560	0.0665	0.0712	0.0732	0.0743	0.0790	0.0809
Shaanxi	0.1599	0.1638	0.1656	0.1720	0.1804	0.2055	0.2235	0.2385	0.2743	0.3082	0.3323
Gansu	0.0619	0.0698	0.0761	0.0845	0.0936	0.1114	0.1276	0.1430	0.1527	0.1680	0.1753
Qinghai	0.0286	0.0317	0.0314	0.0331	0.0333	0.0369	0.0401	0.0445	0.0472	0.0513	0.0522
Ningxia	0.0347	0.0403	0.0434	0.0458	0.0501	0.0587	0.0656	0.0754	0.0806	0.0868	0.0906
Xinjiang	0.0722	0.0820	0.0940	0.0964	0.1073	0.1192	0.1279	0.1516	0.1730	0.1858	0.2144
Zone A	0.1055	0.1148	0.1291	0.1199	0.1228	0.1304	0.1371	0.1466	0.1575	0.1674	0.1768
Zone B	0.1144	0.1052	0.1169	0.1228	0.1298	0.1403	0.1480	0.1608	0.1695	0.1832	0.2032
Zone C	0.1366	0.1438	0.1625	0.1737	0.1857	0.1997	0.2170	0.2338	0.2478	0.2725	0.2962
Zone D	0.0885	0.0930	0.0961	0.1006	0.1066	0.1178	0.1282	0.1391	0.1548	0.1714	0.1837
Zone E	0.1227	0.1393	0.1497	0.1732	0.1871	0.2084	0.2259	0.2474	0.2729	0.2947	0.3126
Zone F	0.0846	0.0978	0.1087	0.1252	0.1460	0.1723	0.2034	0.2341	0.2651	0.3032	0.3223
Zone G	0.0671	0.0759	0.0850	0.0904	0.1004	0.1153	0.1277	0.1473	0.1628	0.1769	0.1948
Zone H	0.0403	0.0415	0.0431	0.0448	0.0446	0.0517	0.0557	0.0589	0.0608	0.0652	0.0665
Zone I	0.1474	0.1595	0.1682	0.1776	0.1944	0.2215	0.2504	0.2825	0.3117	0.3353	0.3581

TABLE IV
DEVELOPMENT LEVEL AND GROWTH RATE OF ANQP BY DIMENSION

Aspect	Dimension		A	B	C	D	E	F	G	H	I
T	New Quality Means of Production	Average Value Growth Rate	0.2051 （5） -4.62%	0.2046 （5） 6.02%	0.2061 （5） -5.3%	0.2043 （5） -8.19%	0.2060 （5） 10.61%	0.2050 （5） 29.58%	0.2048 （5） 24.42%	0.2039 （5） 27.62%	0.2073 （5） 0.93%
O	New Quality Labor Objects	Average Value Growth Rate	0.2954 （3） 20.99%	0.2966 （3） 10.81%	0.2982 （3） 69.52%	0.2985 （3） 7.81%	0.2993 （3） 39.59%	0.304 （3） 31.34%	0.3064 （3） 66.92%	0.3043 （3） 32.93%	0.3093 （3） 8.19%
	New Quality Development Concept	Average Value Growth Rate	0.4155 （1） 35.36%	0.4186 （1） -22.80%	0.4131 （1） 7.42%	0.4148 （1） 20.67%	0.4153 （1） 57.71%	0.4153 （1） 60.05%	0.4191 （1） 11.08%	0.4191 （1） 21.38%	0.4214 （1） 70.23%
	New Quality Laborers	Average Value Growth Rate	0.3284 （2） -36.17%	0.3269 （2） -8.15%	0.3276 （2） -10.6%	0.3245 （2） 1.10%	0.3279 （2） -3.07%	0.3245 （2） 26.82%	0.3244 （2） -5.73%	0.3242 （2） 59.57%	0.3275 （2） 4.52%
E	New Quality Development Environment	Average Value Growth Rate	0.2554 （4） -10.55%	0.2555 （4） 11.36%	0.2566 （4） -7.19%	0.2540 （4） 8.97%	0.2570 （4） 11.05%	0.2565 （4） 24.74%	0.2561 （4） 15.96%	0.2553 （4） -13.81%	0.2576 （4） 2.36%

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